CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-242

FLEXURAL-SLIP FAULTING NEAR PICO CANYON

Los Angeles County, California

by
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INTRODUCTION

The 17 January 1994 Northridge earthquake produced no primary surface rupture that has been identified. Secondary ground-rupture, in the form of bedding-plane slip, has been found in a limited area of the Newhall 7.5-minute quadrangle on the north slope of the Santa Susana Mountains, approximately 20km north of the epicenter (Treiman, 1994). The zone of fault rupture was about 250m long with additional ground fracturing occurring for another 350m to the north (Figure 1). This locality is near the mouth of Pico Canyon, west of the city of Santa Clarita. There is currently no Earthquake Fault Zone in this immediate area, although to the northeast a Zone does exist along the San Gabriel Fault within this quadrangle.

The purpose of this report is to describe the ground rupture that occurred near Pico Canyon and determine whether these faults are sufficiently active and well-defined to be included in an Earthquake Fault Zone under the Alquist-Priolo Earthquake Fault Zoning Act (Hart, 1994).

SUMMARY OF AVAILABLE DATA

The geology of the area of faulting is simple (Treiman, 1986; Winterer and Durham, 1962). Interbedded, well-indurated sandstone and siltstone of the Pleistocene non-marine Saugus Formation is inclined to the northeast at 40° to 60°. This section of tilted strata lies within the north flank of the Pico anticline. The Saugus Formation is unconformably overlain by the flat-lying to gently northeast-dipping sands and gravelly sands of the late-Pleistocene Pacoima Formation, a local fluvial and colluvial basin-fill deposit that is younger than 730,000ka (Treiman, 1982).

The recent faulting is primarily within an area graded for development, although no structures had yet been built where surface rupture occurred. The site geology was mapped in detail by consulting geologists (GeoSoils, Inc., 1988). No faults have been previously identified in this area, although bedding-plane shears are common within the Saugus Formation in the Santa Clarita area. The nearest significant faults are the San Gabriel fault (Holocene active) about 5km to the northeast, the Holser fault (Quaternary) about 5km to the north, and the Santa Susana Fault (Quaternary[1]) about 8km to the south.

Post-earthquake trenching of the bedding-plane faults, by GeoSoils, Inc. (Dave Sherman, personal communication), has documented that the displacement occurred along bedding planes within a 2" to 18" (5cm to 45cm) thick clay bed, and a post-earthquake survey has documented at least 0.4' to 0.5' (12-15cm) of vertical displacement (northeast side up) along the main rupture (Figure 2). Trenching of related fractures to the north (see Figure 3) has been done by Earth Systems Consultants (Patrick Boales, personal communication) and by Seward (1994). [I also briefly viewed these trenches.] These latter trenches showed that the earthquake related fractures to the north were related to shears or faults that are normal to the slope. The trenches also exposed older reverse bedding-plane faults and southwest-dipping reverse faults in the bedrock. There was no direct evidence in the trenches of Holocene faulting, but neither did they entirely eliminate this possibility. Seward (1994) concluded that the closed depression was the result of landsliding. The results of this trenching are further discussed in the section on field observations.

SEISMICITY

Prior to the Northridge earthquake the seismicity of the area had been dominated by aftershocks of the 1971 San Fernando earthquake. The Pico Canyon area was also heavily shaken by a significant pre-instrumental earthquake (the Pico Canyon earthquake) which occurred in 1893 (cited by Richter, 1973). No fault rupture was specifically reported from the 1893 event, although widespread rockfall and fissuring was recorded.

Seismicity from the Northridge earthquake defines a deep (19km to 6km), south-dipping ($\approx 40°$) fault with scattered shallower aftershocks in the upper block (Hauksson and others, 1994). Figure 4 shows seismicity from 1/1/94 to 8/20/94. Although there is no apparent association of epicenters with the flexural-slip faulting, the rupture area is near the northern margin of an area that is more densely populated with epicenters. This may indicate a relatively abrupt change in the degree of deformation from south to north. It is not expected that significant seismicity will be spatially related to the type of relatively shallow ground rupture that is the subject of this report. Bedding-plane faulting of this nature is secondary to the main seismogenic fault displacement at depth and reflects the regional crustal deformation.

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[1]. The eastern end of the Santa Susana Fault had some minor displacement as a result of the 1971 San Fernando earthquake and is included in an Alquist-Priolo Earthquake Fault Zone.

AERIAL PHOTO INTERPRETATION

Prior to grading the only feature of note in the area of faulting was a naturally occurring northwest-oriented closed depression. There is a suggestion in the 1928 and 1952 aerial photos that the depression may be related to a landslide. The depression is a pre-existing feature (J.A. Treiman, 1985, unpublished mapping) that can be seen on pre-earthquake, as well as pre-development aerial photographs. Most of this feature still exists north of the residential development, part having been removed by grading. The depression, about 70m long and 40m wide, lies between the main zone of faulting and a zone of discontinuous ground cracks to the north (Figures 1 & 3). As an alternative to landsliding, this depression may be the result of previous episodes of reverse bedding-plane slip damming the head of the small northeast-draining canyon. A ridge to the southeast (now buried by grading) had a step in it that may also have been related to prior deformation.

Past displacement in the area to the northwest is suggested by several remnants of a gently-sloping geomorphic surface (Figure 1). The larger of these surfaces has been modified by grading for and construction of a 4-million gallon water tank. These surfaces may have been created or preserved by damming of slopewash deposits by reverse bedding displacements or ridgetop settlement. A small colluvial-surface remnant is also partially preserved within one of the active drainages and may be the remains of a similarly dammed sediment accumulation. A notch on a spur ridge southeast of the water tank coincides with recent ground cracks and may be related to previous displacement.

The recent ground rupture (see Figure 1) is partly visible in the post-earthquake aerial photographs, especially in the 1:6,000-scale I.K. Curtis photos (see p.7).

FIELD OBSERVATIONS

Slip occurred along at least five bedding planes exposed in building pads and cut slopes of a residential development (Stevenson Ranch) west of Interstate 5 (see Figure 1). No structures had yet been built on the affected lots. Displacement was consistently northeast-side up (up to 19cm measured) and lateral separations varied from about 4cm right-lateral (near the 8cm vertical measurement) to 7cm left-lateral (at the 37° dip). Left-lateral displacements dominated. [The 19cm vertical measurement was made by visual sighting across the scarp with a tape and is slightly at odds with the approximately 15cm based on post-earthquake survey data (Figure 2). The visual measurement may have been skewed by original slope of the graded pad, or may reflect ground warping not evident in the survey data]. The most continuous rupture extended for about 250m with a general trend of N40°W. As exposed in a bedrock cut slope at its southeastern extremity the fault surface dipped 37°NE (7cm vertical and 7cm left-lateral displacement). Smaller parallel ruptures lay approximately 40-80m to the northeast. One of these was traceable part way up a cut slope at the northern margin of the development. One short 2cm-high scarplet was also observed about 50m to the west. The individual ruptures were clearly compressional in nature and were expressed by a rounded southwest-facing scarp, commonly with a tensional fracture along the upper margin where the scarp was collapsing. This morphology is in contrast to the more common open cracks and fissures, in this and other developments, that were clearly tensional.

To the southeast the fault zone may continue across McBean Parkway. Cracking of the road and a subtle left-lateral displacement (2.5"-3"; 6-8cm) of the median along the Parkway may be related to the fault zone. This, however, is close to a cut/fill boundary. Further to the southeast the zone either dies out or is obscured by man-made fill. Possible fault displacement cannot be differentiated from the effects of fill settlement and shaking cracks in this area.

An anomalous sense of displacement was observed in two localities. At the intersection of McBean Parkway and Steinbeck Avenue the Los Angeles County Engineering Department performed street repairs to correct a warp in the road. Deformation here amounted to 6" to 8" (15-20cm) vertical uplift on the southwest (C. Nestle, L.A. County, personal communication). No surface fractures were noted here and although this locality does not directly align with any individual fractures it is on line with the general zone of faulting and overlies a step in the pre-grading topography. An anomalous sense of offset was also observed where one of the smaller faults crossed Holmes Place. Although this fault showed reverse displacement (northeast side up) in the bedrock cut areas to either side of the road, the road and curb appeared to be downwarped to the northeast. Nevertheless, compression was indicated by shortening of the sidewalk and curb.

North of the development, within the closed depression, surface fracturing was not prominent. Several traverses across this depression found only a few discontinuous fractures in the soil along the southwest side and at the southern end, but none with any measurable vertical displacement. A large bulldozer and backhoe excavation by Seward (1994; T-5) revealed gently to moderately dipping Pacoima Formation with numerous fractures and shears. These included both northeast and southwest dipping reverse faults. None of the bedrock shears could be shown to have moved in the recent earthquake, or even in the Holocene, however the young colluvial deposits in this trench were not adequately logged or observed to preclude Holocene displacement.

A N35°W trend of open soil fractures was found to continue from the northwest end of the closed depression. The fracture zone was best expressed crossing several northeast-trending spurs (coming off of a northwest-trending strike-ridge) but was also traceable through part of the intervening canyons. For about 100m the fracture zone was expressed intermittently by one to two uphill facing scarplets, from 2cm to 10cm high. Minor, discontinuous cracking across spur ridges was observable for another 200m to the northwest. These cracks dipped southwest at the surface (in the soil), normal to the ground surface and appeared to be extensional. They had no measurable vertical displacement.

Four trenches excavated by Seward (1994; see Figure 3) found most of the cracks, north of the depression, to be related to southwest dipping fractures that cut across bedding-planes (within the depth of the trenches). Several of the fractures were open and had been filled with looser sand. Up to 2cm of normal displacement (northeast side up) was observed across these fractures. In one trench (T-4) the southwest-dipping fracture was terminated (at a depth of about 4m) at a prominent bedding plane that could conceal bedding-plane slip.

Older bedding-plane shears were evident in many of the trench exposures. T-2 demonstrated the late-Quaternary folding of the Pacoima Formation, where the bedding changed from an inclination of 37°NE to horizontal within a distance of about 13m. The contact between the Pacoima and Saugus formations was sheared (prior to the 1/17/94 earthquake). Shears were not as evident in T-1.

No cracks of a tectonic origin were visible at the site of a four-million-gallon water tank immediately to the northwest of the last fractures or further to the northwest. A careful traverse was made for at least 500m and a general reconnaissance along trend for another 2km failed to find any cracking other than from shaking or landsliding.

DISCUSSION AND CONCLUSIONS

Faulting certainly occurred along bedding planes during the Northridge earthquake. The zone of reverse bedding-plane faults and fractures in the southern part of the study area is compressional and was in clear contrast to extensional fractures observed elsewhere in the earthquake affected region. The faulting is interpreted to be the result of flexural slip associated with tightening of the Pico anticline. This interpretation is consistent with the uplift and compression of the Santa Susana Mountains as indicated by GPS data (Ken Hudnut, personal communication). Bedding-plane slip in the northern portion of the study area may have ruptured upward across bedding and colluvium as it neared the surface to produce the near-surface normal displacements observed in the trenches. The trench observations are consistent with local deformation within a relatively narrow zone of deformation (perhaps at shallow depth). It is reasonable, on these narrow spur ridges, that shallow bedding-plane shears might turn normal to the slope in response to the reduced confining pressure. Alternatively, the normal displacements may be at least partly a result of ridgetop spreading and downslope movement associated with shaking. Although surface displacements were not detected within the closed depression as a result of the Northridge earthquake, the numerous shallow compressional features suggest that this feature may have formed by the cumulative effect of incremental displacements along multiple bedding-planes. The presence of the depression within the zone of faulting and fracturing suggests that this was not a spatially random rupture occurrence, but that it is a repeatable response to regional deformation. Preserved remnants of older gentler geomorphic surfaces to the northwest are suggestive of previous displacement, but are not compelling.

Explanations besides flexural slip were also considered for the faulting. It is not likely that the displacements are from bedrock rebound due to removal of overburden and triggered by the seismic shaking, since less than thirty feet of bedrock was removed from above the principal rupture. Several consultants with much tract grading experience were contacted and they have not seen rebound occur with even greater removals. There was no removal in the area of ground displacement to the north of the depression. Shaking alone is not a viable explanation for the faulting as these compressional displacements are clearly different from the extensional shaking cracks and fissures here and elsewhere from this event. The closed depression is probably not related to landsliding, based on analysis of the topography and trench exposures. Although landsliding is common in some parts of the Saugus Formation, few have been observed in this part of the section (Treiman, 1986).

Seward (1994) interprets the depression to be a product of landsliding. This mechanism does not explain the presence of closed contours behind (west) of relatively undeformed Pacoima Formation. If the landslide were translational then the surface depression should be underlain by a graben, however Seward's bedrock graben lies further upslope (SW). If the landslide were rotational, then the surface contour closure should be accompanied by backtilted (SW-dipping) bedding rather than the horizontal to NE-dipping beds shown in their trench log. Seward notes the presence of a bedding-parallel shear plane, detected in several borings, that he believes is the landslide failure surface. Alternatively this sheared surface could be the bedding-plane faulting that we are interpreting.

RECOMMENDATIONS

The displacements within the development occurred in conjunction with the Northridge earthquake along a relatively confined group of bedding planes. Ground cracks with a similar sense of displacement to the northwest were related temporally to the faulting and align with the most northeasterly set of faults. The closed depression and notched spurs within this zone of faulting and fracturing is an indication that similar displacements may have occurred in this zone in the past. Therefore, we have faulting that is sufficiently active and well-defined (Hart, 1994). An additional concern, in the case of secondary rupture such as this, is that it not be a random, non-repeatable event. Geomorphic and geologic evidence indicate that such rupture has been repeatable. The relatively confined area of deformation suggests that it is an avoidable hazard.

I recommend incorporating the several bedding-plane faults with confirmed displacement within a new Earthquake Fault Zone. This Zone should also include the closed depression and the more significant fractures to the northwest (see Figure 5). Since subsurface investigation has cast some doubt on the relation of the northwestern cracks to the bedding-plane faulting, only those fractures that showed a clear displacement should be included.

Reviewed; recommenda-
tions approved.
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AERIAL PHOTOGRAPHS USED

Fairchild Aerial Surveys	flight C-300		
1:18,000	b/w	7x9	
frames E-152 & E-153		1928	
GS-EM			
1:24,000	b/w	9x9	
frames 3-24 & 3-25			8-16-47
I.K.Curtis flight 94-111	Northridge EQ		
1:6,000	b/w	9x9	
frames 13-245 & 13-246		1-21-94	
NASA	flight 94-002-02		
1:15,000	b/w	9x9	
frames 484, 485, 504 & 505		1-22-94	
US Department of Agriculture			
1:24,000	b/w	9x9	
AXJ-2K-140 & AXJ-2K-141			11/3/52

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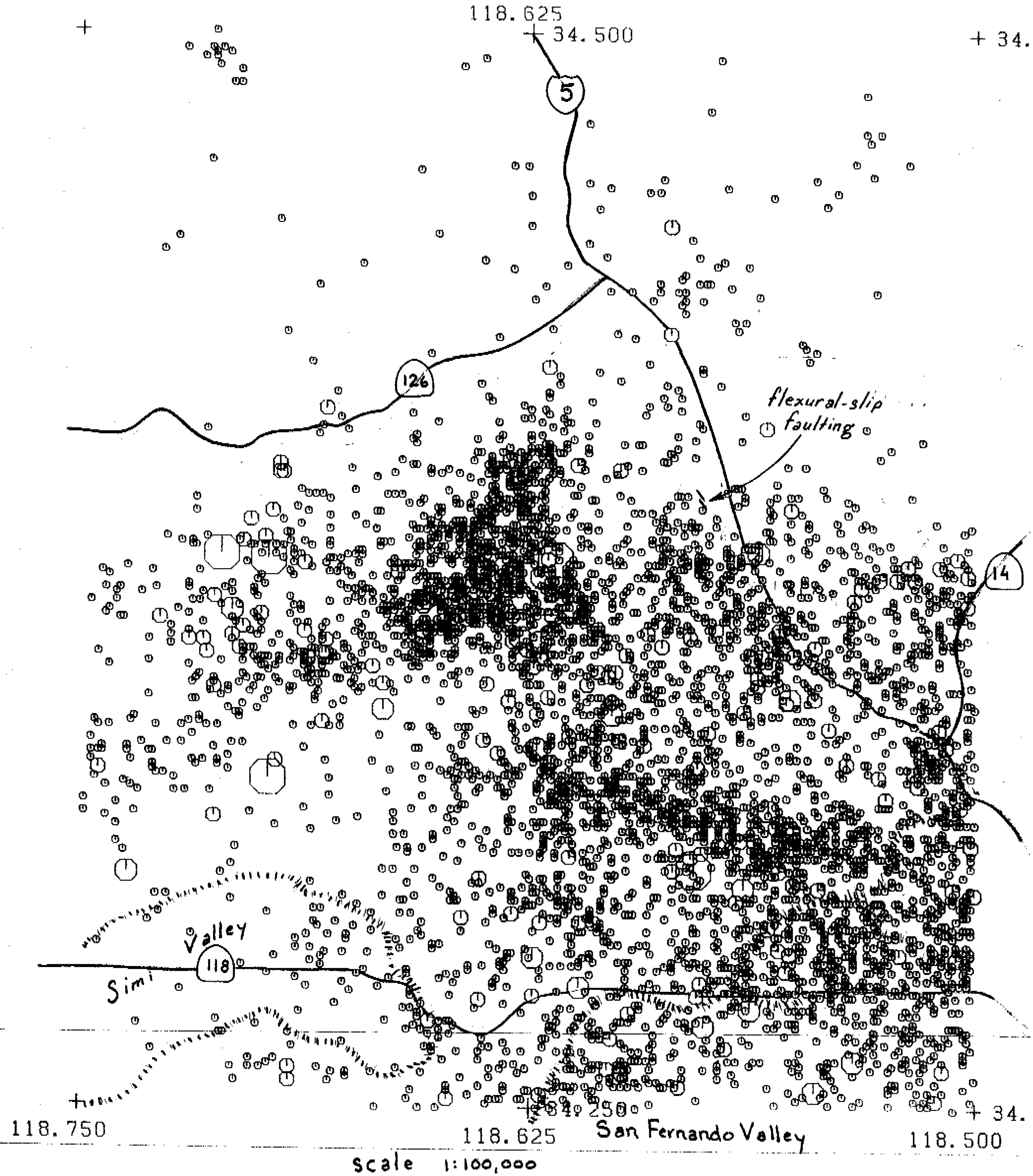

Figure 4. (FER-242) Seismicity in the area of Pico Canyon for the period 1/1/94 to 8/20/94; M2.0 and greater.